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Five Issues

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In the following, five important issues shall be discussed. We believe that their proper handling will greatly contribute to world stability.

We want to emphasize that this paper proceeds along lines which are unusual in science. In science, it is general practice to solve basic problems first, and then to proceed to fill in details.

In the following, five details will be considered: energy, food, climate, war and science. The big basic problems are world government and avoidance of overpopulation. In our opinion, these are at present too difficult to solve, and at the same time, it is much too tempting to accept inadequate solutions. A solution or even an incomplete solution of the five special problems mentioned above will make it easier to attack the bigger problems. Furthermore, the solution of the five problems mentioned contains some scientific and unusual elements. This makes their separate discussion profitable.

Making energy generally available consists primarily of the generation of electricity. As practiced today, this generation runs into two problems.

In the not-too-distant future, there will be a worldwide shortage of some energy sources from which electricity is generated. The present estimated reserves of fossil fuel include one trillion barrels of oil, four thousand trillion cubic feet of natural gas, large reserves of coal in China, Russia and U.S.A., with an equivalent energy content considerably greater than the sum of oil and natural gas reserves.

It is probably possible to calculate total emission of greenhouse gases into the atmosphere whereby generating a global warming debt might defeat the usefulness of the above-mentioned reserves. Therefore, we must look for energy sources without any environmental impact. Fission reactor is one good example with which we have become

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quite familiar, and it is likely that soon the 21st century economy may have to be based on fission.

The most widespread worry is that use of coal contributes to "greenhouse gasses" which tend to retain energy in the atmosphere and is apt to cause a rise in the average temperature. An observed rise of one-third of a degree Kelvin in fifteen years, is not certain enough to have real predictive value. What is more important, the impending shortage of fuel makes the proposed expensive solutions (by taxation) seem less necessary. But the impending shortage of some fossil fuels does make it desirable to look for another energy source. The obvious choice of such an energy source is energy from nuclear reactors. Actually, one big nuclear reactor accident in Chernobyl in 1986 made nuclear reactors unpopular, and they appear to be on the decline in some parts of the world. This is a mistake, in our opinion. The decline should be stopped and reversed. A radical change such as replacing nuclear fission (splitting of big nuclei) by nuclear fusion (fusing small nuclei) seems too difficult and unnecessary. Indeed, explosive energy releases based on fusion are well advanced, while plans for a machine continuing to deliver fusion energy appear much less promising.[‡]

On the other hand, worries about accidents in fission reactors appear exaggerated. In the half-century in which these reactors have been working in several parts of the world, there have been only three major accidents. There was one in England, Windscale in 1956; Three Mile Island in Pennsylvania in 1979; and the third in the Soviet Union in 1986 in Chernobyl. The damage in each of these was estimated in the billion-dollar category, so that incentive for future safety is assured. In the first two, no one seems to have been hurt. In Chernobyl, not much less than 100 were killed as an immediate consequence, including the fighting of the fire that ensued. The radioactive fallout from that accident could not be confined and reached as far away as Turkey. There have been claims of tens of thousands of people having been seriously hurt by this ejected radioactivity, but a conference in Vienna on the ten-year anniversary found that actually the only large-scale damage was due to fear.[§]

It is reasonable to compare the number of casualties divided by the amount of electricity generated. This number is less for fission reactors than for other widespread energy generators such as those burning coal. It might, therefore, make sense to plan future energy generators to be based on nuclear fission. We should also like to suggest that fear of radioactivity should be diminished by effectively eliminating dispersion of radioactivity from fission reactors. This could be accomplished by locating nuclear reactors in loose dry earth a thousand feet underground and by constructing them in such a way that they should have a negative temperature coefficient. (This new concept of underground placement of energy generating reactors needs an economic assessment in particular, in case of an accident, how that scenario compares to reactors operating above the ground. In this case, we need to do two things: 1) Discussion of the projected reactor house; 2) The structure and waste management—Should it be preserved where the waste is produced or be transported somewhere else? Both cases have pros and cons.) In order

‡ Reasonable cost predictions remain high in spite of efforts in Russia and the United States on improvements in the planning of future fusion reactors.

§ In the following months, the number of abortions in Western Europe showed an excess of a few times 10,000, due to unjustified fears that the offspring could suffer from the radioactive fallout generated by Chernobyl.

to reduce the danger, the construction should be such that if reactor temperature increases, its energy output should decrease, and that at a moderately increased temperature, the reactor should stop producing energy. To do this, we should rely on the contribution of slow neutrons to the reactions, and also add an appropriate amount of neutron absorbers, which, due to a resonance, absorb neutrons more effectively in the epithermal than in the thermal regions.

The reactor should be cooled by the inert gas, helium, and could be regulated by the flow of helium. If more helium is pumped, the reactor cools down, and its energy output increases. If too much energy is produced, the reactor heats up and the energy production declines. Thus, the reactor cannot overproduce energy by overheating, and substantial energy production would go on only in a vigorously cooled state.

The generation of electricity would be a two-stage process. One stage, a thousand feet underground, would produce not electricity, but hot helium; the second stage at very shallow depth would transfer the high energy of helium into electricity by a conventional generator, which, being at shallow depth, is easily accessible.

There have been numerous experimental underground nuclear explosions performed in Nevada. It was found that after the explosion, the produced substances are practically immobile in the absence of water. The reactor here described is inherently stable, but even in case of an accident, the radioactivity will stay underground if the earth is dry. The radioactivity from an exploded underground reactor should actually not worry us because resulting heat from radioactivity evaporates any invading water and keeps the residue dry. Thus we have double safety. No uncontrolled reaction or “run-away” could occur because of the negative temperature coefficient, and if such a run-away actually should nevertheless take place, then there will be a lack of means to transport the radioactivity to the surface of the earth.

The functioning of the reactor and the investment in the reactor will not be at risk except through gross errors in the construction or through a most improbable reconfiguration of the underground rock by earthquake or meteor impact. But even in that case, there will be no health damage because the radioactivity will remain confined. Ultimately, if the radioactivity is to reach the surface, the primary cause (earthquake, volcanic flow, or meteorite impact) must itself occur all the way between the surface and the depth of 1,000 feet, which amounts to total destruction due to the external cause rather than the reactor.

Had we located the reactor in solid rock, a splitting of the rock by an earthquake could have brought radioactivity to the surface. By placing the reactor in loose dry earth, an earthquake will leave the earth loose and the radioactivity immobile.

The whole energy-producing process is to be started by a conventional uranium reactor that functions for one or a few years. It produces fission and energy and also an excess number of neutrons. The latter could be used to activate a thorium reactor which is initially incapable, by itself, of maintaining a reaction, but if activated by neutrons, a burning would start as follows: Th^{232} + neutron yields Th^{233}. Th^{233} yields beta + beta + U^{233}. U^{233} + neutron yields fission + neutrons. Th^{232} + neutron yields Th^{233} (as above) and the cycle starts again. Or, alternatively, we could continue to use U^{238} + neutron yields U^{239}. U^{239} yields beta + beta + Pu^{239}. Pu^{239} + neutron yields fission + neutrons. U^{238} + neutron yields U^{239}, and start again.

Thus, both the Th-based and the U-based cycles will work for a second reactor. But to initiate the Th-based cycle, some previous activation by neutrons is necessary, whereas in the case of uranium, the presence of some (fissionable) U^{235} helps in getting the process started. Thus, a breeder as such reactors are called, in thorium, requires a start-up by neutrons from a uranium reactor. The second thorium reactor may activate a third thorium reactor. This could continue in a chain of reactors for a millennium if we so choose. The point in using thorium is that it is much more abundant than uranium and will not be exhausted in 1,000 years.

According to plans, energy production by a reactor and its eventual shutdown should be followed by transporting residual radioactivity to a safe place, for instance, in Nevada. It seems to us that this is the most dangerous phase. A traffic accident in transportation might have catastrophic consequences. It seems to us simpler, less expensive, and, above all, more safe to leave the radioactivity where it has been produced, provided that the original location and configuration have been chosen with care. Some activity may remain significant for a millennium, but it will not be harmful, and eventually safe and profitable applications may develop for radioactivity; the exhausted reactor may be "mined" for its radioactive content.

A few additional remarks are needed. One is that the planned reactors require expert knowledge and careful execution in their original placement. But the subsequent operation, for possibly a considerable number of years, needs little expertise. Thus the use of reactors by the underdeveloped part of the world need not run into any difficulty.

The second point is that only the installation of the reactors will be expensive. Their operation will require little expertise (as stated above) and little expense. The result may be that nuclear energy may become truly competitive.

The number of thorium reactors taking over from a single uranium reactor need not be specified at the beginning. In a chain of reactors, only one reactor (i.e., uranium reactor or thorium reactor) will be active at one time except for the intervals where the reaction is handed over from a reactor to the next. We may guess that the operating cost for one (or two) reactors and the subsequent transformation into electrical energy will have an operating cost of not more than $10 million a year for an output of a thousand megawatts. That would mean $10 per kilowatt year and a couple of cents per kilowatt-hour.

The last figure, of course, has to be multiplied by at least a factor of five since the cost of distribution and the really big cost of building the reactors, have to be added. The competitive nature of the enterprise must ultimately depend on an effective, inexpensive and well-planned way of building the reactors. All we have done here is to indicate how low operating costs have to become in order to make the worldwide application of nuclear reactors feasible.

The third and most important point is that radical military misuse can be eliminated if the reactors are inaccessible (except by dangerous and expensive mining operations). Thus, the planned reactor will not make material available for military stockpiles.[**] (It

[**] The residues might also be used for their plutonium content for military purposes. This danger will increase with the passage of time; but time also may permit the development of appropriate agreements and safeguards.

appears that around the reactor, to avoid its radical military misuse, we can construct some kind of arrangement making access more difficult or at least more obvious.)

We claim that nuclear reactors are clearly the best possibilities for energy production. Other options, like solar energy, hydroelectric energy or geothermal energy, might be applicable for particular local uses, but for big-scale production, nuclear energy is apt to win. And the approach using fission seems to be the easy and inexpensive one.

The one necessary limitation is the question of food supply. We see two possible sources for much more food. One is the exploitation of the oceans. Today's fishing is, in principle, not very different from Paleolithic hunting. When shall we cultivate the oceans?

There is a different approach for more food supply based on our rapid progress in the science of biology. The earliest human civilization made a great impact through the domestication of animals and plants. This required detailed knowledge and study of the mature animals or plants as well as of the connection between parent and offspring. Today, great advantages can be derived from our understanding of inheritance which functions through information carried by one type of organic molecule, deoxyribonucleic acid (DNA). Actually, the most impressive international study of the millions of components of the DNA molecule in humans has been recently completed. The same thing for other forms of life is underway in an impressive manner.

Unfortunately, there are widespread fears associated with newly-bred forms of food supplies because of their conceivably harmful nature. Are scientific developments really more dangerous than the Paleolithic development through trial and error? Need we be really afraid of knowledge and its consequences? It is a reasonable step to study of modifications of DNA (which proceeds spontaneously) and the elimination of undesirable modifications. What Paleolithic man accomplished in millennia, we might perform in a single generation through modern methods of inducing variations, observing the results in the animal or vegetable DNA and its consequences in the resulting organisms.

Environmentalists' objections have been remarkable in connection with possible effects human activities may have on the average temperature of the earth. That changes in climate may have catastrophic consequences is obvious. Indeed, in the last million years, there have been several ice ages. The trend now seems to be reversed and average temperatures appear to be slowly rising. This effect is considered by many as harmful and is attributed to "greenhouse gasses," principally CO_2, generated by the burning of coal.

A possible remedial approach would consist of a two-stage program. First, it would seem reasonable to initiate a big-scale effort on weather prediction. Weather prediction could be extended from only a five-day prediction at present to a two-week prediction to be reached within a few years. This would lead to savings of more than one billion dollars per decade in the United States alone and even more worldwide.[††] The second change we should recommend is to explore the possibility of weather modification, a

[††] Three main profits would be: By predicting the best times for planting and harvesting; by adapting long-range airplane flights to predicted wind velocities; and third, by saving lives and property from predicted floods and hurricanes.

possibility of great potential benefits, including prevention of the claimed worldwide rise in temperature if indeed that proves to be a real danger.

Let's consider first the practice of weather prediction. Weather prediction runs into the difficulty that future weather conditions depend sensitively on small changes at the present time. This phenomenon is encountered in many computational attempts where success has been frustrated by small causes giving rise to big consequences. Indeed, weather phenomena would appear to be ideal examples of calculable predictions by modern computing equipment except for the requirement of accurate initial conditions.

It has been therefore proposed to introduce an atmospheric observational system consisting of two components: Approximately a billion few-inch size, thin-walled plastic spheres[‡‡] at various altitudes all over the atmosphere which might stay afloat for an average of a few months; and secondly, approximately one hundred satellites at an altitude of a few hundred miles, so that they can readily interrogate the spheres floating in the underlying atmosphere. Short, laser pulses from these satellites would be reflected by the small plastic spheres by mounting on the latter a small apparatus called a corner reflector, which returns the reflected radiation into the direction from which it came. The time elapsed between emission and eventual return of the laser light pulses at each satellite will determine the distance of the reflecting objects, while the differential reflectivities will determine the local temperature and humidity at each reflector. One can keep track of the billion small atmosphere-probing spheres with the help of a hundred small satellites, and the data from the satellites also determine the positions and velocities of all of these small transponder objects. Perhaps, the biggest difficulty in execution (about which we are optimistic) is to mass-produce the small transponder-spheres for as little as 10 cents apiece and the satellites for $10M apiece. We expect that the transponder-spheres will be replaced a few times each year and the satellites once every ten years. Thus, the total cost of operating this atmospheric probing system will be approximately $1B per year. Our estimates show that such a system would be good enough to extend weather predictions to two weeks.

Such impressive savings could be further outdone by actually improving the weather. But, weather modification at once runs into the problem of not being to everyone's benefit, or at least of not being perceived as serving everyone's benefit. Yet, if one has arrived at an opinion that burning of coal modifies the weather, it appears to be an obvious necessity to consider other, perhaps compensating, influences. There is, indeed, a straightforward answer to the rising temperature. Distribution of particles of microscopic size in the stratosphere will scatter sunlight back into space and lower the temperature of the earth. Indeed, this effect has been observed in connection with volcanic eruptions.

We believe that it is premature to counteract an expected rise in temperature by distributing exceedingly small scatterers of sunlight in the stratosphere. We do believe, however, that relatively simple experiments should be carried out on small scatterers so that if need arises, such scatterers will be available for appropriate use.

The result should be to lower the temperature of the whole earth. While such a change might be approved by the majority, it may well be objected to by a minority. It seems, to us, necessary to carry out sufficient experiments to predict the effect and then to obtain consent and descent on the basis of predicting the actual changes that will be

[‡‡] Filled with an appropriate mixture of helium and nitrogen.

obtained. It is, of course, impossible to predict what the final decision should be in each case.

Explosives based on nuclear fission used over Hiroshima and Nagasaki ended the Second World War. This fact, together with the development of the hydrogen bomb, has given rise to widespread apprehensions about the damage that will accompany the fighting of a third world war. In many ways, this should be counted only as one more manner in which advancing technology has contributed to the horrors of war. Tanks, airplanes and long-range missiles may make the third world war insupportable even in the absence of nuclear explosives.

There appears to be, however, one circumstance that makes nuclear explosives in themselves very specifically dangerous. That is the element of surprise. Knowledge of nuclear and hydrogen explosives has spread and will in the not too distant future be generally available. In this way, even a relatively small and not highly developed country may inflict truly horrible damage practically anywhere in the world. In other words, the unpredictable nature by which a nuclear war can be started is a qualitatively new element that should deeply worry everyone. We shall discuss a possible countermeasure below, but will first emphasize the dimensions of the problem.

The Pu^{239} that accumulates in fast reactors is used as fuel in slow reactors. It can also be collected in used fuel elements of the slow reactors. Unfortunately, Pu^{239} can also be used as an essential part of nuclear explosives. How does one prevent plutonium theft? The concern is that plutonium can be stolen from the nuclear-energy industry by terrorists for the construction of nuclear bombs. Vast literature exists on this subject discussing large numbers of scenarios of plutonium theft or laser-induced U^{235} extraction from natural uranium. The possibilities cannot be ignored, even though it is quite difficult to assign probabilities of occurrence to nuclear terrorist activities. Such security issues constitute an important part of the impact of nuclear power.

The problem of security for peaceful uses of nuclear energy was discussed in 1973 by Theodore B. Taylor, a theoretical physicist and former bomb designer, in a series of articles in The New Yorker Magazine. In a 1974 book, he gave information on how to make nuclear bombs. His efforts and the resulting publicity have led to better and greatly tightened safeguard procedures. None of these, even if the U.S. and Russia were the only nuclear monopolies, could be one hundred percent safe with regard to plutonium theft.

At present, a laser-based method exists to produce highly enriched uranium where the U^{235} isotope constitutes 90% of the uranium instead of the naturally occurring amount (less than one percent). Highly enriched uranium is strictly for bomb use and is independent of the nuclear power industry. Worldwide use of nuclear energy for electricity production presents other complications with regard to safeguarding fissionable fuel. The usefulness and safety of nuclear energy depend very much on international cooperation in all phases of its peaceful uses. The International Atomic Energy Agency, headquartered in Vienna, Austria, must be strengthened to emphasize the necessity of international cooperation for the safe use of nuclear energy. International cooperation is one of the most important moves toward making the world safe in the nuclear age. Failure or error in the nuclear age could affect the entire world. All of these difficulties are greatly increased by modern emphasis on secrecy. We believe that the introduction of an appropriate amount of openness will help to counteract the great dangers mentioned. We shall return to that important point at the end of our paper.

The danger of nuclear war should be specifically discussed in connection with the United States. Oceans and the general peaceful condition of the Western Hemisphere have provided a limitation to surprises to the United States. This historic advantage cannot last.

The situation was similar in England in the beginning of the 1930s. The British Isles had lost their protection from Europe. This fact played a considerable part in the political development prior to World War II.

One must conclude that the world at large and the United States in particular have a great stake in the establishment of missile defense. Somewhat more generally, one must acknowledge that in the age of military nuclear forces, all nations of the world face a particularly unstable future.

It is our conviction that the development of technology could lead to a better life for everyone. It would be highly desirable if that were true, and particularly if it would apply to stabilize behavior between nations. It is therefore a question of specific importance to diminish and if possible, eliminate the danger of surprise attack by nuclear means. There can be no doubt that this is a difficult question. We claim it is not unsolvable—indeed, we claim that, in the 1970s and 1980s, the U.S. had been on the right track toward a solution, which unfortunately has been abandoned.

The answer is missile defense executed a short time after the missile take-off. At that time, high accelerations are needed which make the take-off much more easily noticed. At that time also, there is less doubt as to responsibility for the launch. Finally, at that time, the intended victim may be uncertain. This last point, however, may be considered an advantage. Indeed, the defensive action is for protection of everyone. The point is, it is for the protection of any city and, therefore, serves the safety of the whole world instead of the safety of any one nation.

Earth-orbiting satellites have to serve to observe the preparation for the launch as well as the launch itself. Furthermore, the satellite should carry the needed counter-missile missiles. Using the rapidly improving methods of observation and the prediction of orbits, the counter-missile missiles could destroy its target by collision or by near-by conventional explosion or even, if need be, by a nuclear explosion.

But how do we know that the purpose of a missile is attack? Our suggestion is that we should assume that in all cases this is so except if the launching of a missile with date, orbit and detailed purpose has been announced appropriately ahead of time. Indeed, the ideal situation would be not to eliminate the launching of missiles but to limit them to internationally cooperative enterprises such as, for instance, weather observation as suggested previously.

It is unnecessary to reiterate the magnificent technical accomplishments that resulted from the science of the Twentieth Century. The previous section contained an appeal to use these same developments for the stabilization of the world. Unfortunately, there is, in contemporary science itself, a negative element that interferes with the realization of the dreams outlined above. That element is secrecy, which, of course, is in itself incompatible with one of the oldest and most important practices of science.

After the Oppenheimer hearings of 1954, Niels Bohr raised a strong protest against the fact that Oppenheimer lost his clearance. Bohr had also a long talk with one of the authors [ET], arguing with all his elaborate convictions against secrecy. He was so convinced of his argument that he did not notice that Edward Teller agreed with him.

As has been said earlier, the essential facts on the hydrogen bomb are practically no longer secret. Unfortunately, we see no way how to end secrecy by sudden and complete action. We do advocate abolishment of secrecy and the re-establishment of openness in science in a thoughtful and gradual manner.

What can be explained simply and clearly in one page cannot be kept secret. Details are less interesting from a general point of view and important only if you want sustained international cooperation. These are also the principles according to which the practical rules of private companies are established.

One point should be particularly emphasized—the simple things that need to be explained can be stated in their essence in one page each. The relativity of time as discovered by Einstein, the unpredictability of the future as discussed by Heisenberg, the release of nuclear energy as demonstrated over Hiroshima, the nature of the energy sources of the universe, all have been disclosed though perhaps not enough emphasis was placed on needed simplicity.

Our general recommendation, as has already been hinted, is not complete openness, but yet sufficient openness that can serve worldwide progress of science and worldwide establishment of rules.

We hope that applications of science as described in earlier sections, including cooperation between nations, will make it easier to approach a final necessary stage. That stage, as we see it, is not uniformity as might be enforced by world government, but maintenance of the differences between nations, which we consider to be a truly attractive part of man's activities. Such differences must be accompanied by patterns of behavior, which will tend to support cooperation and rule out the ultimately destructive function of war.

Therefore, this paper does not offer a solution but only a postponement of a great problem, together with hopes for a continually improving future.

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